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<p>(54) Title: WELDING METHOD, AND WELDING DEVICE FOR USE THEREIN, AND METHOD OF ANALYSIS FOR EVALUATING WELDS</p>		
<p>(57) Abstract</p> <p>Described is a method of automatically welding pipes, comprising welding with a pulsation welding current and monitoring, by means of a sensor, the variations occurring in the arc voltage caused by weld pool oscillations. The occurrence of voltage variations with only frequency components below 100 Hz indicates excessive welding through; the occurrence of voltage variations with only frequency components above 100 Hz indicates insufficient welding through; a welding process showing proper welding through is characterized by the occurrence of voltage variations in two different frequency peaks.</p>		

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Title: Welding method, and welding device for use therein,
and method of analysis for evaluating welds.

The present invention relates to a welding method in which a workpiece is partly melted by means of an electric arc.

Such a method is well-known in practice as a method of construction and is used, inter alia, to interconnect two or more metal workpieces. The workpieces are placed with the sides to be connected in each other's vicinity and are partly melted along these sides by means of an electric arc. The partly melted parts flow together to form a single weld pool; if required, material can be added to the weld pool. After solidification of the weld pool the mutual attachment is a fact. By moving the welding arc along the above sides, with the weld pool moving along with this arc, a welded seam is formed.

15 An important parameter which highly determines the quality of the welded joint formed is the degree of welding through. As used herein, the term "welding through", hereinafter also designated as "penetration", refers to the relative depth over which the welded seam, i.e. the molten and resolidified material, extends into the workpiece. By way of illustrative example, it will be clear that when a butt welded seam is made in plate-shaped workpieces the strength of the weld is insufficient if the welded seam does not fully extend through the plates, and that the seam left between the plates forms a weak point in the construction formed. On the other hand, when during welding the weld pool formed extends too

deeply into the plates, it may happen in extreme cases that the molten material cannot be retained by the plates.

In the ideal case the welded seam extends exactly over the full depth of the plates.

5 A problem arising here is that it is difficult to evaluate from the side of the welding arc how far the weld pool extends through the material. In the case of manual welding the welder can visually observe the weld pool and derive from the observation whether the welding through is
10 sufficient or not, and in case of insufficient or excessive welding through he can immediately take corrective measures. This, however, requires a special amount of experience and skill, and errors are not impossible. In case of automatic welding, such a visual observation and the possibility based
15 thereon to take corrective measures are absent.

Especially in situations in which the quality of the welded joint formed must satisfy high standards, it is therefore necessary to subsequently test the welded seam for welding through. If it is possible to approach the back of the
20 weld, such an inspection can be carried out rather easily by visual observation of this back, if required by means of a camera. This is not always possible, however; especially during welding of pipes such a method of inspection is hardly, if at all, possible.

25 In order to enable the welding quality to be examined in such cases, methods of X-raying the welded seam were developed in the past. These methods, however, are very expensive and time-consuming. Often it is not even allowed to make a next

weld before the preceding weld has been accepted; such a waiting time means a loss of production capacity.

It is therefore an object of the invention to provide a method which deals with the above drawbacks by using the known
5 per se fact that the natural frequency of oscillation of the weld pool reflects the degree of welding through. This known per se fact is described in, e.g., U.S. patent 4,711,986. It generally applies that the natural frequency of oscillation of the weld pool is relatively high when the penetration is
10 incomplete, and that this frequency is relatively low when the penetration is complete. It has been found that under normal conditions of practice the above frequency is above 100 Hz in case of incomplete penetration and is below 100 Hz in case of complete penetration.

15 The above publication only describes a welding process in which welding is applied at a continuous current strength. The weld pool is brought into oscillation by supplying pressure waves of a suitably selected frequency; in a specific embodiment this is achieved by modulating an excitation pulse
20 on the continuous welding current. Subsequently, the frequency of oscillation of the weld pool is measured and processed, which enables detection of the transition from partial to complete welding through.

However, the process as described in the above
25 publication has some drawbacks. The publication proposes to measure the frequency of oscillation of the weld pool by means of light reflected by the weld pool, which, however, requires special complex equipment so that the measurement described cannot be carried out easily by standard welding equipment.

Furthermore, although the process as described in the above publication enables the transition from partial to complete welding through to be detected during the process with time, it is not easy to establish whether the degree of welding
5 through does not increase too much. Subsequent quality inspection and the possibility of optimally controlling the welding process automatically are thus hampered.

The invention also deals with these drawbacks. According to an important aspect of the invention pulsation welding is
10 applied. As used in this art, this expression means that the welding current has a square waveform, which is characterized by two quasi stationary DC levels. When the welding current is equal to the first relatively high DC level (referred to hereinafter as pulsed current), the heat input is so high that
15 material is melting and the weld pool is growing; when the welding current is equal to the second relatively low DC level (referred to hereinafter as base current), the heat input is so low that material is solidifying and the weld pool is shrinking. This is a known per se welding process for plate
20 material.

In the first place, the invention is based on the insight that a good welded seam is provided when during the pulsed current phase complete penetration is attained, while during the base current phase the weld pool shrinks to only partial
25 penetration, and that a pulsation welding process to achieve this is characterized by a relatively low frequency of oscillation during the pulsed current phase and a relatively high frequency of oscillation during the base current phase.

In the second place, the invention is based on the insight that during pulsation welding the weld pool is already brought into oscillation automatically by means of the stepped transitions between the two quasi stationary DC levels, and
5 that it is not necessary then to modulate excitation pulses on the welding current.

In a first aspect, the invention provides a welding method which enables the quality of the welded seam formed to be rapidly determined afterwards in a relatively easy manner.
10 For this purpose, pulsation welding is performed, and during welding a signal representing the arc voltage is measured and stored in a memory or recorded on a carrier. After welding, the signals stored are analyzed to determine whether the degree of welding through was sufficient during the welding
15 process. Here the criterion applies that the frequency of oscillation during the pulsed current phase is sufficiently different from the frequency of oscillation during the base current phase. Since such an analysis can be carried out by a computer, the result can be available very rapidly without the
20 necessity of complicated and expensive equipment of analysis.

It is further an important advantage of this method of analysis that the measuring signal can be simply taken from the power source of the welding process so that a standard welding torch can be used without it being necessary for the
25 welded workpiece to be accessible for inspections, such as X-raying.

In a second aspect, the invention provides a method of analyzing welds made by means of a pulsation welding process. For this purpose, a measuring signal representing the arc

voltage occurring during welding, which measuring signal is stored in a memory or recorded on a carrier, is read out of this memory or carrier and analyzed with respect to the occurrence of two peaks in the frequency spectrum.

5

It is further an object of the invention to provide a method which enables automatic production of welded seams of good quality. Based on the above insights, pulsation welding is performed, and during welding a signal representing the arc
10 voltage is measured. This signal is analyzed in real time with respect to the occurrence of two peaks in the frequency spectrum. The welding process is controlled on the basis of the result of this analysis.

It is observed that within the scope of the present
15 invention the term "a signal representing the arc voltage" also comprises, e.g., the arc current

Further aspects, features, and advantages of the present invention will become apparent from the following description of preferred embodiments of the method and device according to
20 the invention, in which reference will be made to the accompanying drawing in which:

Fig. 1 is a diagrammatic representation of a device for producing and analyzing a weld;

Figs. 2A, 2B, and 2C are diagrammatic cross-sectional
25 views of a weld;

Figs. 3A and 3B show the oscillation modes of the weld pools illustrated in Figs. 2A and 2B;

Figs. 4A and 4B show the frequency spectra belonging to the oscillation modes shown in Figs. 3A and 3B;

Figs. 5A and 5B show the voltage and current curves as a function of the time during the implementation of a method according to the invention;

Figs. 6A-6C show different stages of a weld pool during a cycle of a method according to the invention;

Fig. 7 shows a frequency spectrum of the oscillation of a weld pool during the implementation of a method according to the invention;

Fig. 8A shows the voltage and current curves as a function of the time in case of insufficient welding through;

Fig. 8B shows a frequency spectrum of the oscillation of a weld pool during a welding process shown in Fig. 8A;

Fig. 8C shows the voltage and current curves as a function of the time in case of excessive welding through;

Fig. 8D shows a frequency spectrum of the oscillation of a weld pool during a welding process shown in Fig. 8C;

Fig. 9 is a diagrammatic representation of an embodiment of a device according to the invention, intended for analyzing welds produced;

Fig. 10 is a diagrammatic representation of an embodiment of a device according to the invention, intended for monitoring a welding process; and

Fig. 11 is a diagrammatic representation of an embodiment of a device according to the invention, intended for the automatic implementation of a welding process according to the invention.

Since a pulsation welding process is commonly known per se, this process will be explained only in brief, with reference to Fig. 1. Fig. 1 diagrammatically shows a plate-

shaped workpiece 1, e.g. of steel, which is electrically connected to a first output terminal 11 of a power source 10. A welding electrode 2 is held in the vicinity of the plate 1, e.g. manually or in a welding robot. The welding electrode 2
5 is electrically connected to a second output terminal 12 of the power source 10. In general, the second output terminal 12 is negative with respect to the first output terminal 11. The welding electrode 2 is a non-fusing electrode, e.g. of tungsten, the end of which is suitably designed and is mounted
10 in a nozzle 3 of a welding torch 4 through which a protective gas 5 of a suitable composition, e.g. argon and/or helium, flows. In the protective gas 5 a welding arc 6 burns between the welding electrode 2 and the plate 1, which introduces so much heat into the plate 1 that a part of the plate material
15 is melted and forms a weld pool 7.

Since the nature and the structure of the power source 10 and the welding torch 4 are no subject of the present invention and those skilled in the art do not need knowledge thereof for a proper understanding of the present invention,
20 while for the application of the present invention use may be made of commonly known structures for that power source and welding torch, these will not be described in more detail.

When the welding electrode 2 and the plate 1 are moved relative to each other, the weld pool 7 will move with the
25 welding electrode 2 along the plate 1, with a trace (bead) of molten and resolidified plate material 8 being left. As will be clear to those skilled in the art, additional material may be added to the weld pool by holding an end of a bar of

additional material in the vicinity of the arc, but, for simplicity's sake, this is not shown in Fig. 1.

Figs. 2A-2C diagrammatically show two plates 21 and 22 to be connected together, positioned with their sides against each other. By means of a welding electrode, not shown for simplicity's sake, a weld pool 27 is formed which extends in both plates 21 and 22. When the welding electrode is moved along the above sides, i.e. at right angles to the plane of the paper, the welding bead then formed will connect the two plates 21 and 22 together. In the figures the original contours of the plates are shown in dotted lines.

Fig. 2A shows a situation in which the heat supplied is insufficient to melt the two plates 21 and 22 sufficiently so that the depth d of the weld pool 27 is less than the thickness H of the two plates 21 and 22. Within the scope of the present invention, this situation is designated by the term "partial penetration". Such a weld does not provide optimum strength properties: in the first place, because the weld is thinner than the surrounding plate material and therefore intrinsically weaker than the plates, in the second place, because the slit 28 left underneath the weld forms a notch between the plates in the welded construction, which notch, in case of alternating load, may easily lead to a crack.

Fig. 2B shows a situation in which the heat supplied is just sufficient to melt the two plates 21 and 22 sufficiently so that the depth d of the weld pool 27 is just as large as the thickness H of the two plates 21 and 22. Within the scope of the present invention, this situation, the most favorable

situation, is designated by the term "complete penetration".
In practice, d may slightly exceed H .

Fig. 2C shows a situation in which the heat supplied substantially exceeds the amount of heat required for complete
5 penetration. Consequently, the weld pool 27 is so large that it is sagging by gravity and threatens to drop out of the plates 21, 22. The "sagged" weld shown in Fig. 2C is already weaker than the weld shown in Fig. 2B and is therefore undesirable. Moreover, if the liquid metal actually leaked out
10 of the weld, a hole would be formed in the structure, which is of course quite unacceptable. It is therefore important to control the welding process in such a manner that the situation shown in Fig. 2C is prevented. Within the scope of the present invention, this situation is designated by the
15 term "excessive penetration".

It will be clear that it is not difficult to optically view the "sagging" weld shown in Fig. 2C from the welding arc side, but once this situation occurs during welding, its restoration, at least at the place in question, is no longer
20 possible owing to a change in the welding parameters. This of course applies to a higher degree if the heat supply increases so much that a hole is burned in the structure. Nor is it difficult to optically establish that the situation shown in Fig. 2C does not occur, but it is difficult to distinguish
25 between the situations of Figs. 2A and 2B.

According to the invention the distinction between the situations of Figs. 2A and 2B can be made on the basis of the frequency of oscillation of the weld pool, since in the situations of Figs. 2A and 2B the weld pool behaves

differently with respect to oscillations. This is illustrated in Figs. 3A-B.

Fig. 3A shows the extreme positions of the weld pool in an oscillation mode in case of partial penetration. It can be shown that the frequency of oscillation f_p (Hz) may then be expressed by the equation

$$f_p = 5.84 \sqrt{\frac{\gamma}{\rho_l}} D_p^{-3/2} \quad (1)$$

Fig. 3B shows the extreme positions of the weld pool in an oscillation mode in case of complete penetration. It can be shown that the frequency of oscillation f_f (Hz) may then be expressed by the equation

$$f_f = 1.08 \sqrt{\frac{\gamma}{H\rho_s}} D_f^{-1} \quad (2)$$

In the above formulas:

- γ is the surface tension of the liquid metal (N/m);
- ρ_l is the density of the liquid metal (kg/m³);
- ρ_s is the density of the solid metal (kg/m³);
- H is the plate thickness (m);
- D_p, D_f is the equivalent diameter of the weld pool (m).

In the case of partial penetration D_p is defined as the diameter of a circle the surface of which is equal to the surface of the weld pool. In the case of complete penetration D_f is defined as the diameter of a cylinder the content of which is equal to the content of the weld pool.

When the values of the above quantities, as they will occur under practical conditions, are filled in in formulas (1) and (2), it appears that f_p is always above 100 Hz, while f_f is generally even below 50 Hz.

This will be illustrated by means of a practical example of a weld in structural steel; for this material the following applies:

$$\gamma \approx 1.0 \text{ N/m};$$

5 $\rho_l \approx 7.0 \cdot 10^3 \text{ kg/m}^3;$

$$\rho_s \approx 7.5 \cdot 10^3 \text{ kg/m}^3;$$

At a plate thickness of $H \approx 4 \text{ mm}$ a heat input of about 6 kJ per cm weld length is typically applied, which can be obtained at

10 an arc voltage $V \approx 15 \text{ V},$

$$\text{a current strength } I \approx 80 \text{ A (effective), and}$$

$$\text{a forward velocity } v \approx 1.2 \text{ mm/s.}$$

It should be considered in this regard that the process efficiency η is about equal to 60%.

- 15 If the heat input is chosen relatively low so as to obtain partial penetration, it appears that D_p is about equal to 5.8 mm; from formula (1) it then follows that $f_p \approx 155 \text{ Hz}$. If, however, the heat input is chosen relatively high so as to obtain complete penetration, it appears that D_f is about equal
- 20 to 5.3 mm; from formula (2) it then follows that $f_f \approx 37 \text{ Hz}$.

According to the invention the weld pool, due to the arc pressure variations resulting from the stepped current variations, is brought into oscillation in the modes as illustrated in Fig. 3, and it is possible to measure the

25 frequency of oscillation of the weld pool without directly observing the weld pool itself. As a result of the oscillation of the weld pool, the welding arc length effectively varies at the same frequency. If the power source is arranged as electric source, so that the welding current remains

substantially constant in case of arc length variations, welding arc length variations cause arc voltage variations. If the power source is arranged as voltage source, so that the arc voltage remains substantially constant in case of arc length variations, welding arc length variations cause welding current variations. These current and voltage variations can be measured in a relatively simple manner.

Preferably, the power source is arranged as electric source, and the voltage variations are detected. As illustrated in Fig. 1, a first input terminal 31 of an arc voltage sensor 30 is suitably connected to the first output terminal 11 of the power source 10, and a second input terminal 32 of the arc voltage sensor 30 is connected to the second output terminal 12 of the power source 10. Preferably, the sensor 30 comprises a low-pass filter 33 having a cut-off frequency of, e.g., about 250 Hz, so as to eliminate the influence of high frequency noise from the power source 10. An output 34 of the sensor 30 is coupled to a data processor 40, preferably a data acquisition system on the basis of a computer, which may suitably be provided at its input with an A/D converter 41. Since the data acquisition system used therefor is known per se and standard available and knowledge of its operation is not necessary for a proper understanding of the present invention, the data processor 40 will not be described in more detail.

It is also possible that the output signals of the sensor 30 are first recorded as an intermediate step on a carrier, such as a magnetic tape, and that at a later stage of

analysis the recorded signals are read from the carrier and supplied to the data processor 40.

The data processor 40 can process the stream of entering voltage signals directly, i.e. in real time, but it can also
5 store the entering voltage signals in a memory 42 for later and/or delayed processing.

In a first embodiment of the invention, the data processor 40 is only used to display frequency information on a display device 43, such as a viewing screen, for an
10 inspector. An example of such a diagrammatic representation of frequency information is the frequency characteristic, shown in Figs. 4A and 4B, of the voltage signals as obtained by means of the arrangement, shown in Fig. 1, in the situations of Fig. 2A and Fig. 2B, respectively. The diagrams of Figs. 4A
15 and 4B horizontally show the frequency in Hz and vertically show the relative contribution of the frequency components in arbitrary units. This frequency characteristic is obtained by arranging the data processor 40 to implement a Fourier transform and represents the welding current which occurred at
20 a test weld with the following parameters:

current strength 60 A;

trigger pulses 300 A, 6 ms broad, repetition frequency 5 Hz;

arc voltage 15 V;

protective gas: helium

25 forward velocity 1.2 mm/s

weld depth attained $d = 4$ mm

plate material: steel Fe360

thickness $H = 4$ mm (complete) or 6 mm (partial).

When the diagrams of Figs. 4A and 4B are compared with each other, some clear and essential differences are noticeable.

In the first place, in the case of partial penetration
5 the frequency components are almost exclusively in the range of 150-220 Hz, with peak values near 200 Hz, while in case of complete penetration the frequency components are almost exclusively in the range of 30-80 Hz, with a sharp peak near 50 Hz. This fully corresponds to the above formulas (1) and
10 (2).

In the second place, in the case of complete penetration the height of the highest peak is substantially higher than the height of the highest peak in the case of partial penetration. This can be explained by the fact that in the
15 case of complete penetration all points of the weld pool surface move in phase with each other, so that effectively more influence is exerted on the arc length than in the case of partial penetration.

20 It will be clear from the foregoing that it is quite possible to discriminate between partial and complete penetrations on the basis of the frequency information in the arc voltage. As far as purposes of analysis are concerned, it is therefore possible to establish whether a weld made
25 satisfies the requirements as to penetration: in fact, if throughout the duration of the welding process the recording of the arc voltage shows a frequency information corresponding to complete penetration (Fig. 4B), the weld can be accepted. It is difficult, however, to control the welding process on

the basis of this information only, i.e. to take corrective measures during welding in the case of deviations being found with respect to complete penetration. This is in particular the case with roboted welding in which it is hardly, if at all, possible to move the welding torch a little backward so as to restore partial penetration to complete penetration.

In a welding method according to the invention, welding is therefore performed with pulsating current. The principle of pulsation welding is illustrated in Fig. 5, which figure shows the recording of current I (Fig. 5A) and voltage V (Fig. 5B) in an example of the welding method according to the invention applied to a steel plate 4 mm in thickness at a forward velocity of 0.5 mm/s. During a first part (H) of the welding cycle the current is relatively high, also referred to hereinbelow as pulsed current I_H ; consequently, the arc voltage is relatively high as well. During a second part (L) of the welding cycle the current is relatively low, also referred to hereinbelow as base current I_L ; consequently, the arc voltage is relatively low as well. In the given example, the period of time t_H of the first part of the cycle, also referred to hereinbelow as pulse duration, is about 200 ms, and the period of time t_L of the second part of the cycle, also referred to hereinbelow as base duration, is about 800 ms. In this example, the pulsed current I_H is 160 A, the base current I_L 28 A.

These conditions are so selected that the base current is insufficient to maintain a weld pool, while the pulsed current is more than sufficient to maintain a weld pool. This has the result that during the first part of the cycle, also referred

to hereinbelow as melting phase, the melting bath 7 grows, the pulse duration t_H being so selected that at least complete welding through is obtained. This is illustrated in Fig. 6A, in which the maximum extent of the weld pool 7, as it occurs
5 at the end of the melting phase, is designated by reference numeral 71.

During the second part of the cycle, also referred to hereinbelow as solidification phase, the weld pool 7 shrinks to a size d which is less than H , i.e. incomplete welding
10 through. In this case, however, there is no question of the above drawbacks of incomplete welding, since the material underneath the still liquid material has been liquid but has now solidified, so that the slit 28 is absent. This is illustrated in Fig. 6B, in which the minimum size of the weld
15 pool 7, as it occurs at the end of the solidification phase, is designated by reference numeral 72, and the just solidified material 73 is hatched.

In a next melting phase the weld pool 7 grows again to complete welding through, as designated by reference
20 numeral 74 in Fig. 6C. It is clearly indicated in this figure that the welding electrode 2 has meanwhile moved relative to the plate 1, or conversely, so that the place where complete welding through 74 is obtained, has moved relative to the preceding welding through 71 as well.

25 The final result of the repetition of the above cycle is that the weld considered as a whole has a continuous character of sufficient depth, although a repeated solidification pattern 75 can be recognized therein, which, however, has no detrimental effect on the weld quality.

It has been found, as clearly shown in Fig. 5B, that the transitions from I_H to I_L , and vice versa, are capable of bringing the weld pool surface into oscillation, without separate excitation pulses being required therefor. If the welding parameters are correctly adjusted, the weld pool, during each melting phase, will therefore be in the situation of complete welding through illustrated in Figs. 2B and 3B, in which the frequency spectrum of the arc voltage will be as shown in Fig. 4B, while during each solidification phase the weld pool will be in the situation of partial penetration illustrated in Figs. 2A and 3A, in which the frequency spectrum of the arc voltage will be as shown in Fig. 4A. The resulting frequency spectrum relating to an integration time which is large relative to the current cycle is shown in Fig. 7. Two separate peaks can be clearly distinguished therein: a first peak at about 50 Hz relating to the melting phase, and a second peak at about 125 Hz relating to the solidification phase.

According to the invention the frequency spectrum shown in Fig. 7 with two peaks is characteristic of a good weld, at least a weld having a good penetration. A weld showing incorrect penetration is distinguished by the occurrence of only one peak in the frequency spectrum, as illustrated in Fig. 8. Fig. 8A shows the current and voltage curves in case during the pulse duration of the current cycle only partial penetration occurs; Fig. 8B shows the associate frequency spectrum, in which the fact that the frequency spectrum substantially only has components in the frequency range above 100 Hz, usually in the form of only one essential peak, is

characteristic of this situation. Fig. 8C shows the voltage and current curves in case even during the base duration of the current cycle complete penetration occurs; Fig. 8D shows the associate frequency spectrum, in which the fact that the frequency spectrum substantially only has components in the frequency range below 100 Hz, usually in the form of only one essential peak, is characteristic of this situation. In this situation there is an enormous risk of a sagging weld or even melting through.

10 The data of Fig. 8 have been obtained from the same test weld as that of Fig. 5, with the understanding that the data of Figs. 8A-B were obtained at the beginning of the welding process when the plate 1 was still cold, while the data of Figs. 8C-D were obtained when the plate 1 had been
15 considerably heated after some time. The data of Fig. 5 were obtained in an intermediate time phase.

Fig. 9 illustrates a first embodiment of a welding process according to the invention, in which the same or comparable parts as in Fig. 1 are designated by the same reference numerals. Welding takes place by means of a power source 10 arranged to supply a pulsation welding current. In this case the manufacture of a weld can be fully trusted to a welder (or welding robot), but during welding a signal
25 representing the arc voltage is measured by means of the sensor 30 and is recorded by means of a recorder 44 on a magnetic tape 45.

Fig. 9 further illustrates a method of analyzing the welds made. When the weld is ready, the magnetic tape 45 is

read by means of a reader 46, and the signals read are input to a data processor 40. The data processor 40 is arranged, by way of example, to carry out a Fourier transform on the signals received and to display the frequency spectrum of the arc voltage signals on a display 43. An inspector evaluates the frequency spectrum displayed, and on the basis of the degree of welding through determined by means of the frequency characteristic, i.e. the occurrence or non-occurrence of two peaks in the frequency spectrum the inspector accepts or rejects the weld made.

An advantage of recording the arc voltage signals is that these signals can be stored for a longer period of time so as to enable, e.g., supervision of the inspector or reexamination of the weld.

It is observed that the recorder 44 and the reader 46 can be integrated into a recorder/reader.

Fig. 10 illustrates a second embodiment of the method and device according to the invention intended to be used in manual welding, in which during the welding process the welder is provided with a signal relative to the degree of welding through. The output signals of the sensor 30 are presented in a simple data processor 50 to two band-pass filters 51 and 52, the first band-pass filter 51 having a pass band of about 100-250 Hz, and the second band-pass filter 52 having a pass band of about 20-100 Hz. It will be clear that instead of the first band-pass filter 51 a high-pass filter having a turnover frequency at 100 Hz may be used as well if the sensor 30, as observed above, is provided with a low-pass filter 33 having a

turnover frequency of about 250 Hz. It is further possible that the sensor 30 is an integrated part of the data processor 50.

The output signals of the filters 51, 52 are presented to
5 rectifiers 53, 54, respectively. The rectifiers 53, 54 thus provide an output signal the voltage level of which is representative of the presence of arc voltage variations having frequencies in the range of 100-250 Hz and 20-100 Hz, respectively. These DC signals can be evaluated by a computer,
10 but in the simple structural variant shown in Fig. 10 the output signals of the rectifiers 53, 54 are presented to first inputs 57, 58 of comparators 55, 56, respectively. The comparators 55, 56 have two inputs 59, 60, to which adjustable reference voltages or threshold voltages are presented. Each
15 comparator 55, 56 provides at its output 61, 62 a high signal when the voltage received at the first input 57, 58 is higher than the threshold voltage and a low signal when the voltage received at the first input 57, 58 is lower than the threshold voltage.

20 The outputs 61, 62 of the comparators 55, 56 are coupled to control inputs 63, 64 of a sound signal generator 65 which is arranged to give the welder, by means of a headphone 66, three different sound signals:

a first sound signal, e.g. a signal having a relatively low
25 frequency when at the first control input a high signal and at the second control input a low signal is received, as a sign that the penetration is incomplete;
a second sound signal, e.g. a signal having a relatively high frequency when at the first control input a low signal and at

the second control input a high signal is received, as a sign
that the penetration is excessive;
a third sound signal, e.g. a signal having an alternating
frequency and a relatively low sound intensity when at both
5 the first control input and the second control input a high
signal is received, as a sign that the penetration is just
sufficient.

It will be clear that the nature of the three different
sound signals is not relevant and may be adjusted, if desired,
10 by the welder at this own discretion.

The embodiment shown in Fig. 10 provides the welder, in a
very simple manner, with information about the degree of
welding through, and on the basis of the information received
the welder, using his own craftsmanship, can suitably change
15 the welding parameters to arrive at an optimum weld.

It is observed that instead of filtering the entering
signals the processor could also be arranged to subject these
signals to a Fourier transform.

It is further observed that the voltage signals may also
20 be recorded to enable subsequent use of the analysis/control
method according to the invention discussed with reference to
Fig. 9.

Fig. 11 illustrates a further structural variant of the
25 present invention with which it is possible to automatically
produce welds with a proper welding through, which method
particularly enables pipes to be automatically welded
together. For this reason the automatic welding device 80

illustrated in Fig. 11 is considered to be the most important use of the invention.

The automatic welding device 80 illustrated in Fig. 11 comprises a welding robot 81 which is arranged to move, under control of a control member 82, the welding electrode 2 at a predetermined forward velocity v along a seam to be welded in a workpiece 1, shown in Fig. 11 as being a pipe. In a variant, the welding robot 81 is arranged to move the workpiece 1 along the electrode 2, which may then be kept stationary. Such a welding robot 81 is known per se in practice, and details of its structure and of the mechanism for following the seam to be welded do not form part of the present invention. Since, moreover, those skilled in the art do not require knowledge of these details for a proper understanding of the present invention, the welding robot 81 will not be described herein in more detail. It suffices to observe that, conventionally, the control member 82 is arranged to move the welding robot 81 at a preadjustable forward velocity.

The automatic welding device 80 further comprises a power source 10 which, as already discussed above, is arranged to supply a pulsation welding current and has a first output 11 for coupling to the pipe 1 and a second output 12 for coupling to the welding electrode 2. The power source 10 further has a control input 13 for receiving control signals, as will be explained in more detail.

The automatic welding device 80 further comprises a welding sensor 30 the inputs 31 and 32 of which are coupled to the outputs 11 and 12 of the power source 10 for measuring a signal representing the arc voltage, as already discussed with

reference to Fig. 1. An output signal of the sensor 30 is presented to a data processor 83 which also functions as central control unit. The data processor 83 has a first control output 84 coupled to the control input 13 of the power source 10 and a second control output 85 coupled to the control input 86 of the control member 82. It is observed that the data processor 83 and the control member 82 may form one whole, in which case the second control output 85 and the control input 86 are omitted.

10 The data processor 83 is arranged to continuously monitor the degree of welding through of the weld made, on the basis of the frequency characteristic of the signals received from the sensor 30. For this purpose the data processor 83 may be arranged, e.g., to filter the signals received from the sensor 30 in a manner as discussed with reference to Fig. 10, or to carry out in real time a Fourier transform on the signals received from the sensor 30. In order to control the welding process, the data processor 83 is arranged to distinguish between the following three situations which may occur:

(1) The situation in which the detected frequency characteristic comprises two different frequency peaks indicative of the occurrence of sufficient welding through during the pulse phase und sufficient solidification during the solidification phase, as discussed with reference to Figs. 5-7. The data processor 83 is arranged not to correct the welding parameters in this case.

(2) The situation in which the detected frequency characteristic comprises only one frequency peak, namely in a frequency range above 100 Hz, indicative of the occurrence of insufficient welding through during the pulse phase, as discussed with reference to Figs. 8A and 8B. The data processor 83 is arranged to change the welding parameters in this case to effect a larger heat input.

(3) The situation in which the detected frequency characteristic comprises only one frequency peak, namely in a frequency range below 100 Hz, indicative of the occurrence of excessive welding through, as discussed with reference to Figs. 8C and 8D. The data processor 83 is arranged to change the welding parameters in this case to effect a reduced heat input.

The change in the heat input may take place in different ways, namely by transmitting suitable control signals to the power source 10 and/or the control member 82, as will be clear to those skilled in the art. By way of example, it is mentioned here that in order to effect a larger heat input the data processor 83 may be arranged to transmit, via its first control output 84, a control signal to the power source 10 to adjust:

a higher base current and/or
a higher pulsed current and/or
a longer pulse duration,
and/or to transmit, via its second control output 85, a

control signal to the control member 82 to adjust a lower forward velocity.

It is of course possible that one user prefers another welding parameter change than another user, in which

5 connection the position of the weld and the material of the workpiece may be relevant. Preferably, therefore, the data processor 83 is provided with a selector switch, not shown for simplicity's sake, with which the user can select the welding parameter(s) to be changed.

10 It is observed that the above situations (2) and (3) are error situations that must be avoided, and that the data processor 83 will aim at always maintaining situation (1). Consequently, the data processor 83 is arranged not only to make corrections when the above situations (2) and (3) occur,
15 but also to make corrections once it is detected that one of those situations threatens to develop. Such a development can be detected, e.g., as the reduction of the relative contribution to one of the two frequency peaks in the situation (1).

20

It is further observed that the above-mentioned limit of 100 Hz is a limit observed under practical conditions for different welding materials. It is not deemed impossible, however, that in a given specific case the above limit is at
25 another frequency. The fact, however, will then always be that the occurrence of excessive welding through is characterized by the occurrence of weld pool oscillations at frequencies only in a first relatively low frequency range, and that the occurrence of insufficient welding through is characterized by

the occurrence of weld pool oscillations at frequencies only in a second relatively high frequency range, the second frequency range being properly distinguishable from the first frequency range, usually by a factor of 2. It will be clear to
5 those skilled in the art that it is possible to determine the actually occurring frequency ranges by way of experiment and to input a suitable limit frequency to the data processor 83.

Preferably, however, the data processor 83 is self-learning, i.e. arranged to determine in a learning mode, by
10 means of test welding on a workpiece, the frequency characteristic of weld pool oscillations at the time of insufficient welding through and to store it in a memory, and further to determine the frequency characteristic of weld pool oscillations at the time of excessive welding through and to
15 store it in a memory. In an operation mode the data processor 83 may then compare the frequency characteristic of the signals received from the sensor 30 with the frequency characteristics stored in the memory.

20 It will be clear to those skilled in the art that it is possible to change or modify the given embodiment of the device according to the invention, without departing from the inventive concept or the scope of protection. Thus, for instance, it is possible that the invention is used in
25 pulsating plasma welding. It is also possible, if desired, e.g. when the damping of the oscillations is relatively strong, to support the oscillations during the base current phase and/or during the pulsed current phase by superposing trigger pulses on the welding current.

C L A I M S

1. A welding method, comprising partly melting a workpiece by means of an electric arc, performing pulsation welding, measuring a signal representing the arc voltage during welding, and storing the measured signal in a memory or
5 recording it on a carrier.
2. A welding method, comprising partly melting a workpiece by means of an electric arc, performing pulsation welding, measuring a signal representing the arc voltage during
10 welding, and generating, on the basis of the form of the frequency spectrum of said signal, a signal indicative of the degree of welding through.
3. A welding method according to claim 2, wherein the
15 generated signal is a sound signal.
4. A welding method according to claim 2 or 3, wherein the measured signal is also stored in a memory or recorded on a carrier.
20
5. A method of analyzing welds made by means of a pulsation welding process according to claim 1 or 4, wherein the measuring signal representing the arc voltage, which is stored in said memory or recorded on said carrier, is read out of
25 said memory or said carrier and is analyzed with respect to the frequency spectrum thereof.

6. A method of analysis according to claim 5, wherein a weld (portion) to be tested is rejected if the frequency spectrum has only one relevant peak and is accepted if the frequency spectrum comprises two relevant peaks.

5

7. A method of analysis according to claim 6, wherein the two relevant peaks in the frequency spectrum are on both sides of 100 Hz.

10 8. A welding method, comprising partly melting a workpiece by means of an electric arc, performing pulsation welding, measuring a signal representing the arc voltage during welding, analyzing said signal in real time with respect to the frequency spectrum, and controlling the welding process on
15 the basis thereof.

9. A welding method according to claim 8, wherein, if the frequency spectrum has only one relevant peak at a relatively low frequency range, the heat input of the welding process is
20 reduced, and wherein, if the frequency spectrum has only one relevant peak at a relatively high frequency range, the heat input of the welding process is increased.

10. A welding method according to claim 9, wherein the
25 change in the heat input is effected by changing the forward velocity and/or by changing the base current and/or by changing the pulsed current and/or by changing the pulse duration.

11. A device for making welds, comprising:
a power source (10) arranged to supply a pulsation welding
current with a first output terminal (11) for connection to a
workpiece (1) to be welded and a second output terminal (12)
5 for connection to a welding electrode (2);
an arc voltage sensor (30) with a first input terminal (31)
intended to be connected to the first output terminal (11) of
the power source (10), and a second input terminal (32)
intended to be connected to the second output terminal (12) of
10 the power source (10), and an output terminal (34) for
supplying signals indicative of the voltage variations
occurring during the welding process as a result of weld pool
oscillations.
- 15 12. A device according to claim 11, wherein the output
terminal (34) of the arc voltage sensor (30) is coupled to an
input of a magnetic tape recorder (44).
13. A device for analyzing welds, comprising:
20 a magnetic tape reader (46); and
a data processor (40) for receiving the signals read by the
magnetic tape reader (46).
14. A device according to claim 13, wherein the data
25 processor (40) is arranged to carry out a Fourier transform on
the signals received, and to display the frequency spectrum of
the arc voltage signals on a display (43).

15. A device according to claim 11, wherein the output terminal (34) of the arc voltage sensor (30) is coupled to an input of a data processor (50), comprising:
- 5 two band-pass filters (51, 52), the first band-pass filter (51) having a pass band of about 100-250 Hz, and the second band-pass filter (52) having a pass band of about 20-100 Hz;
- rectifiers (53, 54) coupled to the outputs of the filters
- 10 (51, 52);
- first inputs (57, 58) of comparators (55, 56) coupled to the outputs of the rectifiers (53, 54);
- second inputs (59, 60) of the comparators (55, 56), to which adjustable reference voltages or threshold voltages are
- 15 presented; and
- control inputs (63, 64) of a sound signal generator (65) coupled to the outputs (61, 62) of the comparators (55, 56), said generator being arranged to give three different sound signals by means of a headphone (66) in dependence on the
- 20 conditions of the control inputs (63, 64).
16. An automatic welding device (80), comprising:
- a welding robot (81) arranged to move, under control of a control member (82), a welding electrode (2) and a seam to be
- 25 welded in a workpiece (1), e.g. a pipe, relative to each other at a predetermined forward velocity;
- a power source (10) arranged to supply a pulsation welding current, provided with a first output (11) for coupling to the workpiece (1) and a second output (12) for coupling to the

welding electrode (2), and further provided with a control input (13) for receiving control signals;
an arc voltage sensor (30) having a first input terminal (30) coupled to the first output terminal (11) of the power
5 source (10), a second input terminal (32) coupled to the second output terminal (12) of the power source (10), and an output terminal (34) for supplying signals indicative of the voltage variations occurring during the welding process as a result of weld pool oscillations;
10 a data processor (83) coupled to the output terminal (34) of the arc voltage sensor (30);
said data processor (83) having a first control output (84) coupled to the control input (13) of the power source (10), and a second control output (85) coupled to a control
15 input (86) of the control member (82).

17. An automatic welding device according to claim 16, wherein the data processor (83) is arranged to carry out a Fourier transform in real time on the signals received from
20 the sensor (30).

18. An automatic welding device according to claim 16, wherein the data processor (83) is provided with:
two band-pass filters (51, 52), the first band-pass
25 filter (51) having a pass band of about 100-250 Hz, and the second band-pass filter (52) having a pass band of about 20-100 Hz;
rectifiers (53, 54) coupled to the outputs of the filters (51, 52); and

first inputs (57, 58) of comparators (55, 56) coupled to the outputs of the rectifiers (53, 54);
adjustable reference voltages or threshold voltages being applied to second inputs (59, 60) of the comparators (55, 56).

5

19. An automatic welding device according to any of claims 16-18, wherein the data processor (83) is arranged to change, by means of suitable control signals at the control output (84) and/or the control output (85), the heat input of
10 the welding process in response to the characteristic of the signals received from the sensor (30).

20. An automatic welding device according to claim 19, wherein the data processor (83) is provided with a selector
15 switch which enables the user to select the welding parameter(s) to be changed.

21. An automatic welding device according to any of claims 16-20, wherein the data processor (83) is arranged to
20 determine, in a learning mode, the frequency characteristic of weld pool oscillations at the time of insufficient welding through and to store it in a memory, and further to determine the frequency characteristic of weld pool oscillations at the time of excessive welding through and to store it in a memory,
25 and to subsequently compare, in an operation mode, the frequency characteristic of the signals received from the sensor (30) with the frequency characteristics stored in the memory.

22. A device according to any of claims 11-21, wherein the sensor (30) comprises a low-pass filter (33) having a cut-off frequency of, e.g., about 250 Hz.

- 5 23. A device according to any of claims 11-22, wherein the power source (10) is arranged to additionally superpose trigger pulses on the welding current during the base current phase and/or during the pulsed current phase.

1/9

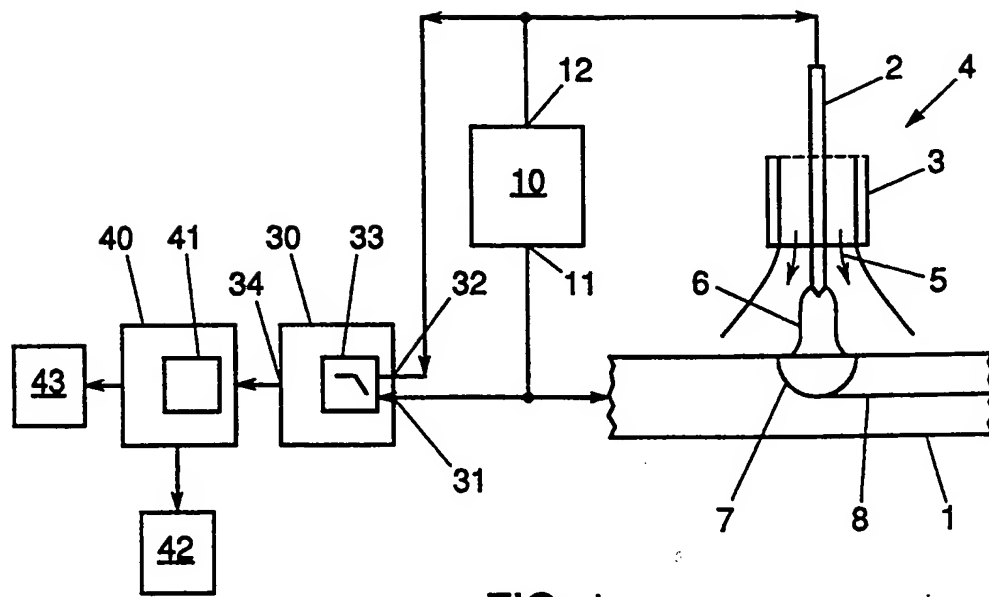


FIG. 1

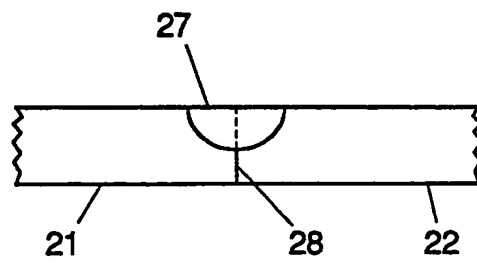


FIG. 2A

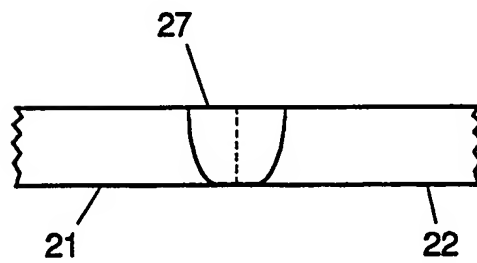


FIG. 2B

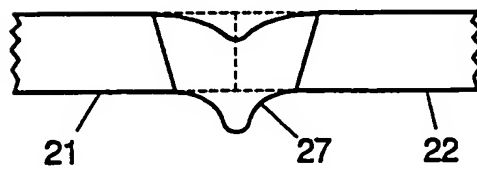


FIG. 2C

2/9

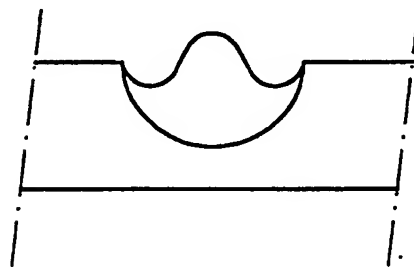
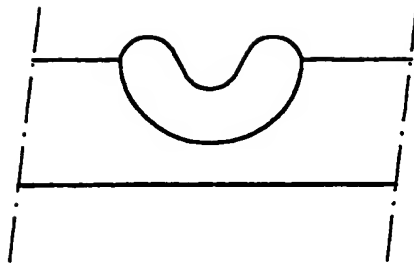


FIG. 3A

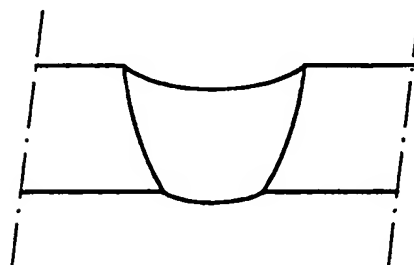
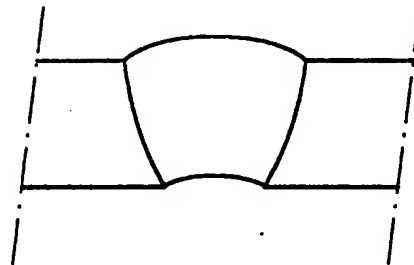


FIG. 3B

3/9

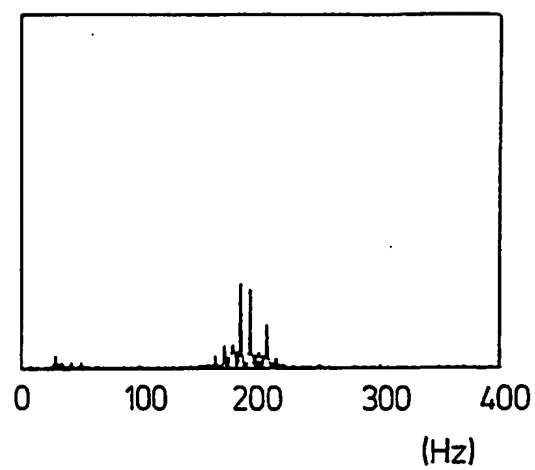


FIG. 4A

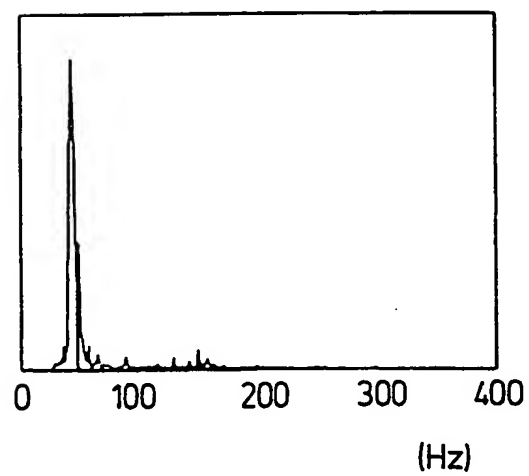


FIG. 4B

4/9

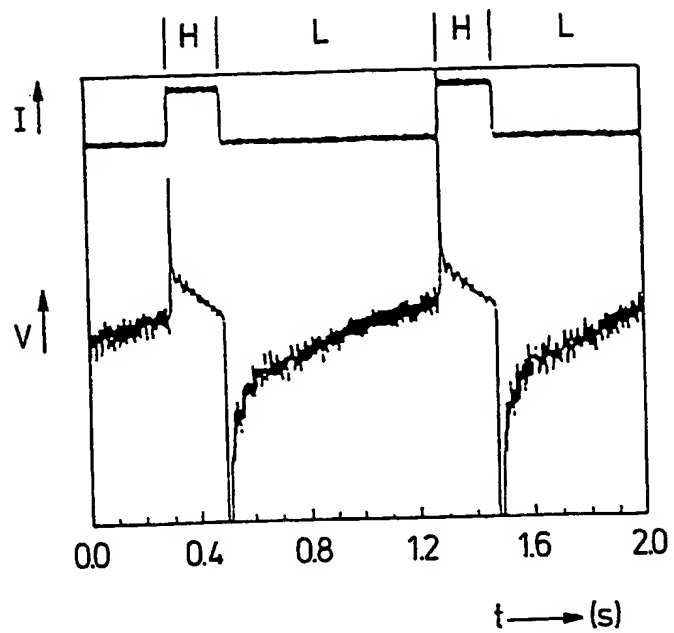


FIG.5A

FIG.5B

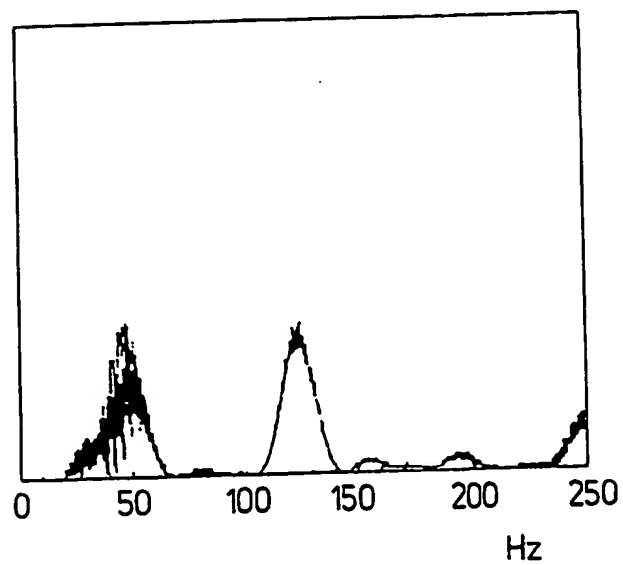


FIG.7

5/9

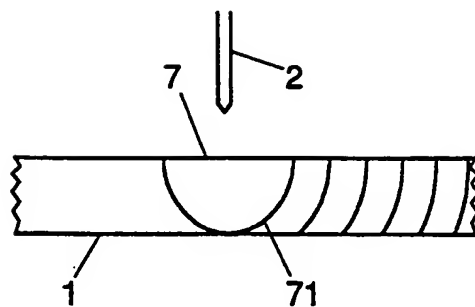


FIG. 6A

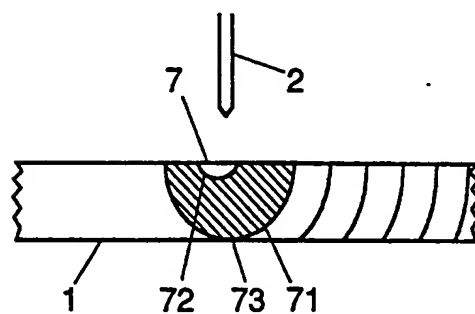


FIG. 6B

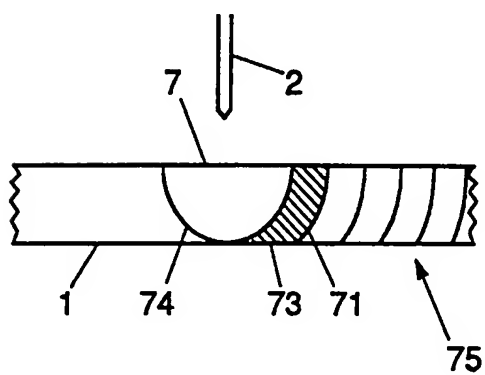


FIG. 6C

6/9

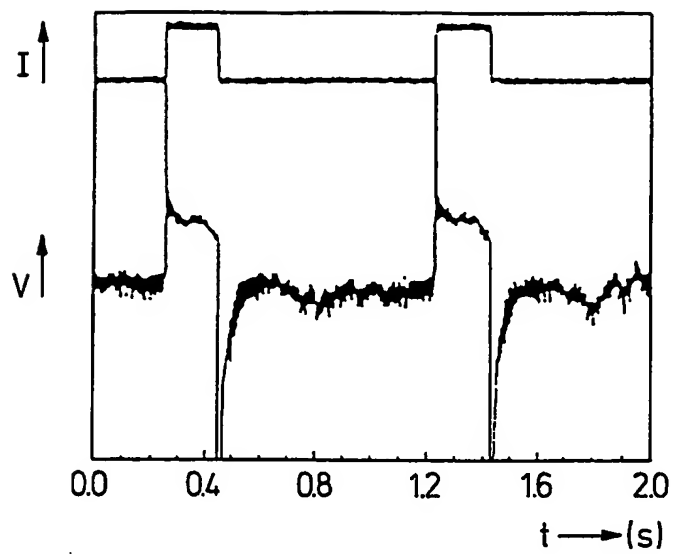


FIG.8A

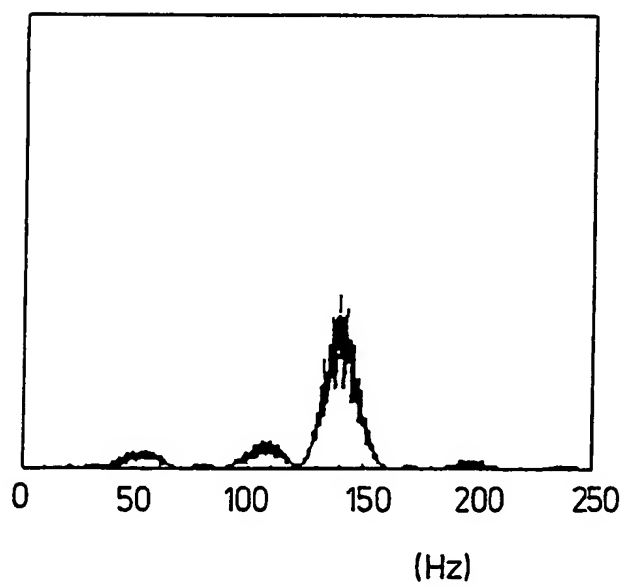


FIG.8B

7/9

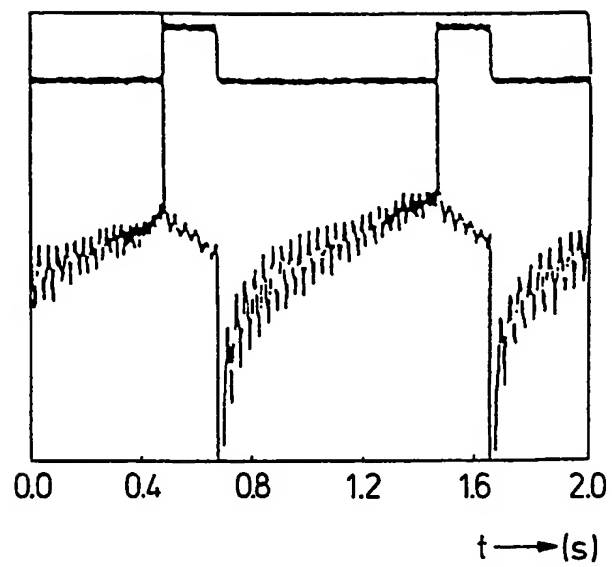


FIG.8C

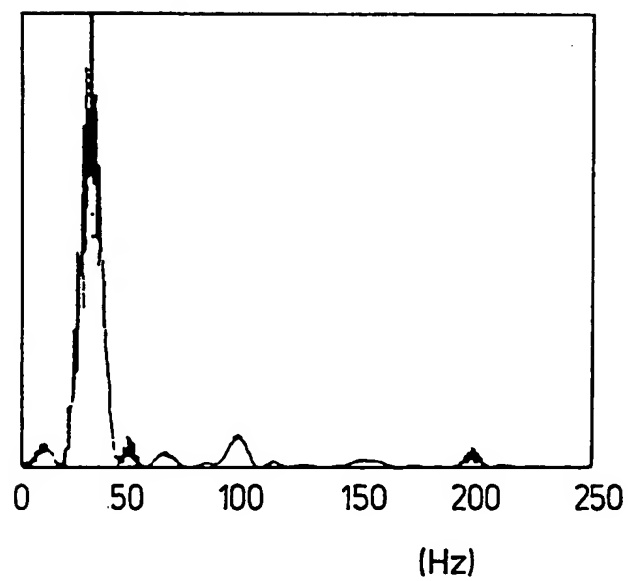
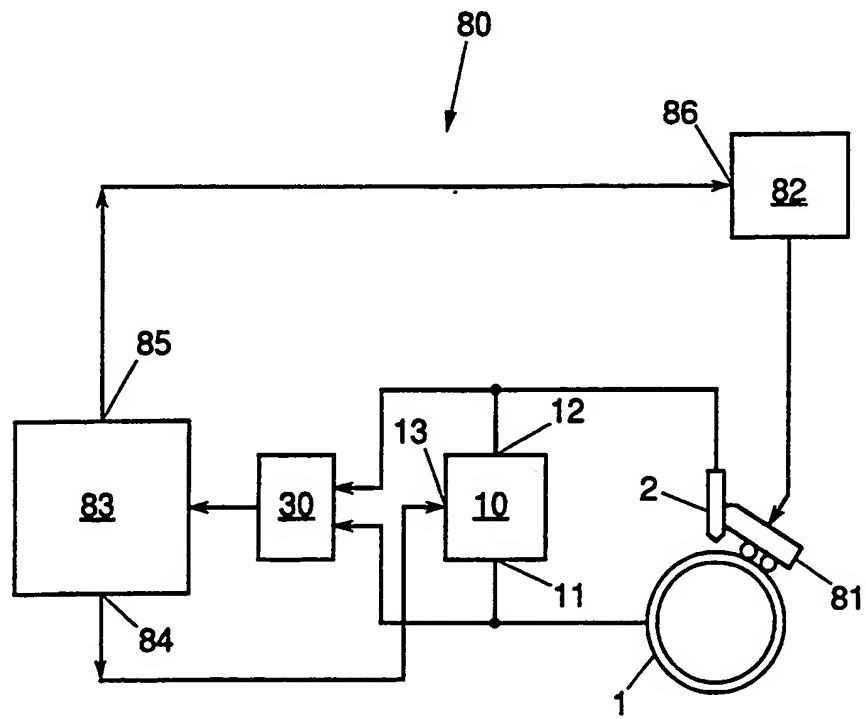
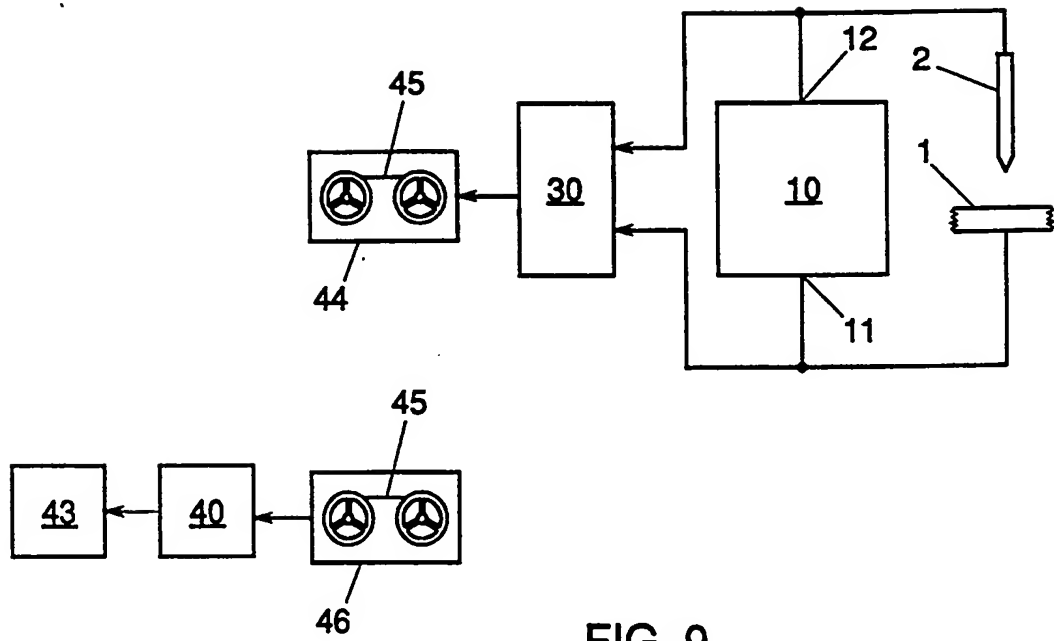


FIG.8D

8/9



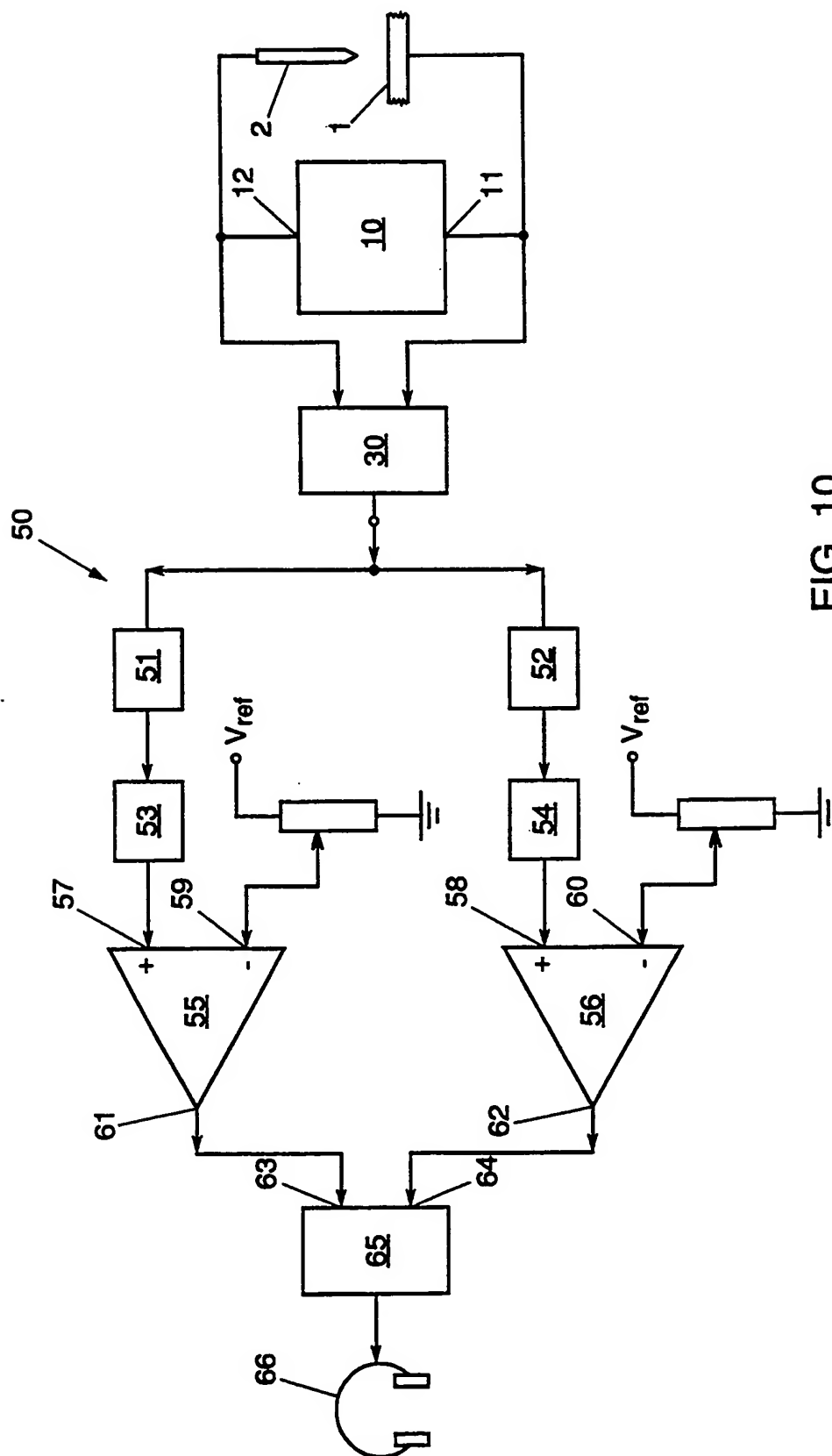


FIG. 10

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL 95/00208

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B23K9/095

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP-A-0 333 195 (HITACHI LTD) 20 September 1989	1,2,4,5,8
Y	see column 9, paragraph 2 - column 15, last paragraph; figure 1 ---	3,4,11,14,16,17
Y	US-A-5 306 893 (MORRIS ET AL.) 26 April 1994 see column 1, last paragraph - column 3, line 2; figure 2 ---	3,11,14,16,17
Y	DE-A-28 13 260 (MESSER GRIESHEIM GMBH) 18 October 1979 see page 5; figure ---	4
A	GB-A-2 210 691 (GENERAL ELECTRIC COMPANY) 14 June 1989 see claims 1,6-9 ---	1-10
	--- -/-	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

4 September 1995

Date of mailing of the international search report

08.09.95

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Authorized officer

Herbreteau, D

INTERNATIONAL SEARCH REPORT

International Application No

PCT/NL 95/00208

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>WELDING JOURNAL, vol. 72, no. 8, 1993 pages 428S-434S, XIAO ET AL. 'Weld pool oscillation during gta welding of mild steel' see the whole document -----</p>	1-23

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/NL 95/00208

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0333195	20-09-89	JP-A- 1237076 DE-D- 68910712 DE-T- 68910712 US-A- 4943701	21-09-89 23-12-93 28-04-94 24-07-90
US-A-5306893	26-04-94	NONE	
DE-A-2813260	18-10-79	NONE	
GB-A-2210691	14-06-89	US-A- 4859830 DE-A- 3833188 FR-A- 2625456 JP-A- 1157792	22-08-89 20-04-89 07-07-89 21-06-89